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NOTICE

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Navy Case No. 73984

METHOD FOR IMPROVING ELECTROMAGNETIC SHIELDING PERFORMANCE OF COMPOSITE MATERIALS BY ELECTROPULSING

This patent application is co-pending with related patent application entitled "Method for Improving Electromagnetic Shielding Performance of Composite Materials By Electroplating" filed on the same date as this application.

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for Governmental purposes without the payment of any royalties thereon or therefor.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

The present invention relates generally to electromagnetic (EM) shielding, more particularly to an electropulsing method for improving the EM shielding performance of a composite material having semi-conductive or conductive filler particles suspended in a non-conductive resin.

(2) Description of the Prior Art

The EM environment encountered in commercial/military applications grows ever more "noisy" as the number of electronic components on a given platform increases. Further, the current desire to use strong, lightweight materials in construction of shielded structures provides an incentive to develop composite materials offering good EM shielding performance that will not degrade over time. To be useful for a range of applications, the composite must have a low resistivity, be resistant to chemical attack, immune to shock (both thermal and mechanical), machinable, moldable and usable in high temperature environments (e.g., greater than 200° C). The composite must further be capable of being utilized in commercial and military applications to include aircraft and shipboard environments. Accordingly, the composite must be lightweight, corrosion resistant when connected to metal structures (e.g., aluminum) and must provide an EM shielding performance at least as good as the present compounds that incorporate aluminum, carbon, stainless steel and nickel-plated carbon fillers. Composites incorporating these materials have been shown to severely degrade over time and exposure to marine/corrosive environments.

Prior U.S. Patent No. 5,066,424 issued to Dixon et al. discloses certain oxides and catalytic behaving materials that "self-adjust" their electrochemical electromotive force. Such adjustment is either by oxygen manipulation or other charge transfer thereby making them extremely attractive in minimizing corrosion due to the dissimilar galvanic potentials. These composites display good EM shielding properties when connected to materials that are dissimilar with respect to the galvanic table. Because the performance of the composite material is not as good, larger quantities of composites are needed for similar shielding properties of the device. This negates any light weight advantages of using the plastic composites. However, still higher levels of EM performance are desirable before these composites will be accepted as replacements for pure metals and alloys in terms of EM shielding performance.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the present invention to provide a method of improving the EM shielding performance of a composite material.

Another object of the present invention is to provide a method of improving the EM shielding performance of a composite material that will be used in a marine environment.

Other objects and advantages of the present invention will become more obvious hereinafter in the specification and drawings.

In accordance with the present invention, a method of improving the electromagnetic (EM) shielding performance of a composite material is provided. The composite has conductive and semi-conductive filler particles suspended in a non-conductive resin. The filler particles make up 0-40 weight percent of the composite. The composite is subjected to an exponentially decaying pulse from an energy source such that the energy of the pulse is less than that required to cause localized melting of the composite. In a preferred embodiment, the resin is a preselected weight percent of a matrix material selected from the group consisting of a polyether etherketone (PEEK) polymer and a polycarbonate polymer, and the filler particles are made up of 0-10 weight percent conducting nickel flake particles and 0-20 weight percent of non-corrosive semi-conducting indium tin oxide particles. In the preferred embodiment, the pulse is a 5 MHz continuous wave pulse having a damping factor in the range of 10-20 and a total energy of approximately 1.5 millijoules.

BRIEF DESCRIPTION OF THE DRAWING(S)

Other objects, features and advantages of the present invention will become apparent upon reference to the following description of the preferred embodiments and to the drawings, wherein:

FIG. 1 is a time domain trace in terms of voltage and current of an exponentially damped 5 MHz continuous wave pulse used in a preferred embodiment of the present invention;

FIG. 2 is a time domain trace in terms of power of the exponentially damped 5 MHz continuous wave pulse shown in FIG. 1;

FIG. 3 is a graph of shielding effectiveness before and after pulsing for the ITO, nickel flake, PEEK example;

FIG. 4 is a graph of shielding effectiveness before and after pulsing for the ITO, nickel flake, polycarbonate example;

FIG. 5 is a graph of shielding effectiveness before and after pulsing for the graphite fiber, polycarbonate example;

FIG. 6 is a graph of shielding effectiveness before and after pulsing for the graphite fiber, nickel flake, polycarbonate example; and

FIG. 7 is a graph of shielding effectiveness before and after pulsing for the nickel coated graphite, polycarbonates example.

DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

The composite material improved by the method of the present invention is comprised of a filler molded into a resin. The filler is composed of conducting and semi-conducting oxide particles, fiber or flakes suspended in the resin comprised of a polymeric material matrix. A class of such composite materials is disclosed by Dixon et al. in U.S. Patent No. 5,066,424, which is hereby incorporated by reference. However, it will be readily understood by one of ordinary skill in the art that other composite materials will have their EM shielding performance improved by the method of the present invention. Several examples of additional composite materials will be given in the description to follow.

In accordance with the present invention, the composite material of choice is subjected to an EM pulse from a controllable source of such energy. The choice of energy source is not a limitation of the present invention. The pulsing frequency may range from DC to light, however, pulsing at or near DC may infuse too much heat energy into the composite material. It is critical that the total energy imparted by the EM pulse be less than what would be required to cause any localized melting within or on the surface of the composite. Further through experimentation, it was found that the greatest improvements in shielding performance were achieved when the EM pulse was a rapidly or exponentially decaying pulse. In this way, a high peak current would be applied to the composite while the exponential decay of the pulse maintained total energy within the critical limits.

In the examples and results to follow, the resin was selected to be either a polyether etherketone (PEEK) polymer or a polycarbonate polymer. Fillers which were evaluated included graphite fibers and flake, nickel-coated graphite fibers, carbon particles, iron oxide, indium/tin oxide (ITO) particles, ITO particles with graphite fibers, ITO/Ni-flake, and combinations of the above. Based on the composites tested, the preferred filler composition consists of two elements: (1) nickel because of its inherent low resistivity and its corrosion resistance properties in combination with the ITO, and (2) ITO which along with the nickel provides excellent corrosion resistance. The semiconductor (ITO) also increases the overall conductivity of the composite thereby increasing the EM shielding effectiveness. The preferred percentages of the fillers by weight for the nickel are from 0% to 10% and for the ITO are from 0% to 20%. Preferred percentages by weight of other fillers mentioned above are from 0% to 20%. It is expected that other combinations of metallic and semi-metallic filler particles (such as silver-coated nickel, silver-coated aluminum, 400 series stainless steel, etc.) and polymers may also have their EM shielding performance similarly improved.

For all of the examples, the EM pulse was generated using a 5 MHz damped cosine (or other continuous wave) EM current source simulator capable of subjecting the composites to a peak current of 150 amperes. The EM pulse current was injected into the samples in such a way that the entire 150 amp peak current flowed through the sample. The 5 MHz current was exponentially damped with a damping factor (Q) of 15 $\pm$ 5. In this way, the majority of the current occurred within the first 3 microseconds (μsec). A longer duration of high level currents may cause the composite to overheat and melt. The overheating would be undesirable, therefore a 3 μsec or less duration was used. The resulting total energy imparted by such an EM pulse is 1.43 millijoules. The time domain trace of the exponentially damped 5 MHz pulse used is shown in FIG. 1 in terms of voltage and current, and is shown in FIG. 2 in terms of power. It is to be understood that other waveforms, frequencies and powers may be used depending on the sample size (i.e., larger sample sizes can dissipate more heat energy than smaller sample sizes) and application. Note that the above described exponentially decaying damped cosine waveform is typical of (naval) shipboard EM coupled currents and voltages and is also representative of industrial/commercial EM levels. However, other EM pulses are expected to provide similar improvement in material performance.

EXAMPLES AND RESULTS

The improvement in EM shielding performance for five examples will now be presented. The five example composites are:

1) 10 weight percent nickel flake
   15 weight percent ITO
   75 weight percent PEEK

2) 10 weight percent nickel flake
   15 weight percent ITO
   75 weight percent polycarbonate

3) 40 weight percent graphite fibers
   60 weight percent polycarbonate

4) 20 weight percent graphite fibers
   10 weight percent nickel flake
   70 weight percent polycarbonate

5) 15 weight percent nickel coated graphite fibers
   85 weight percent polycarbonate

A reduced DC resistivity is one indicator of improved EM shielding performance. Table 1 shows the before and after DC resistivities for the five examples subjected to the EM pulse described above and shown in FIGs. 1 and 2. Note that all five examples improved substantially after pulsing.

Table 1. Comparison of Measured DC Resistivities of Samples Before and After Pulsing Treatment

EXAMPLE NO.	MATERIAL	BEFORE RESIST. (Ω-cm)	AFTER RESIST. (Ω-cm)	IMPROVEMENT (dB)
1	ITO, Ni-Flake, PEEK	>2M	6.0	>100
2	ITO, Ni-Flake, Polycarbonate	123	10.2	22
3	Graphite, Polycarbonate	58.1	10.8	15
4	Graphite, Ni-Flake, Polycarbonate	293	9.9	29
5	Nickel Coated Graphite, Polycarbonate	>60K	245	>48

Shielding effectiveness (SE) is defined as the reduction in magnetic and/or electric filed strengths caused by the shielding material. It is the measure of the quality of the EM performance of that material. Conventional units of SE are decibels (dB). The SE of a material relies on three types of losses: reflection, absorption, and re-reflection of the EM fields. The losses are due to the reflection at the first boundary, absorption through the material, and reflection at the second boundary, respectively. Table 2 shows the post-pulsing SE improvement for each of the five examples at 1 MHz.

Table 2. Measured Shielding Effectiveness at 1 MHz

EXAMPLE NO.	MATERIAL	BEFORE SE (dB)	AFTER SE (dB)	IMPROVEMENT (dB)
1	ITO, Ni-Flake, PEEK	0	40	40
2	ITO, Ni-Flake, Polycarbonate	10	31	21
3	Graphite, Polycarbonate	2	20	18
4	Graphite, Ni-Flake, Polycarbonate	0	22	22
5	Nickel Coated Graphite, Polycarbonate	0	3	3

The improvement in shielding effectiveness over a range of frequencies is given for examples 1-5 in FIGs. 3-7, respectively. In FIGs. 3-7, each dashed line trace indicates measured shielding effectiveness of the composite before being subjected to the pulsing as described above, while each solid line trace indicates measured shielding effectiveness after the composite was subjected to the pulsing.

The advantages of the present invention are numerous. The EM shielding performance of a composite material having conducting and semi-conducting materials in a non-conducting polymeric matrix is greatly improved by EM pulsing. Long-term evaluation of pulsed examples indicates that the improvements are permanent, i.e., EM characteristics do not change appreciably over time or after exposure to marine/corrosive environments.

It will be understood that many additional changes in the details, materials, steps and arrangement of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention.

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METHOD FOR IMPROVING ELECTROMAGNETIC SHIELDING PERFORMANCE OF COMPOSITE MATERIALS BY ELECTROPULSING

ABSTRACT OF THE DISCLOSURE

A method of improving the electromagnetic (EM) shielding performance of a composite material is provided. The composite has conductive and semi-conductive filler particles suspended in a non-conductive resin. The filler particles make up 0-40 weight percent of the composite. The composite is subjected to an exponentially decaying pulse from an energy source such that the energy of the pulse is less than that required to cause localized melting of the composite.

FIG. 1

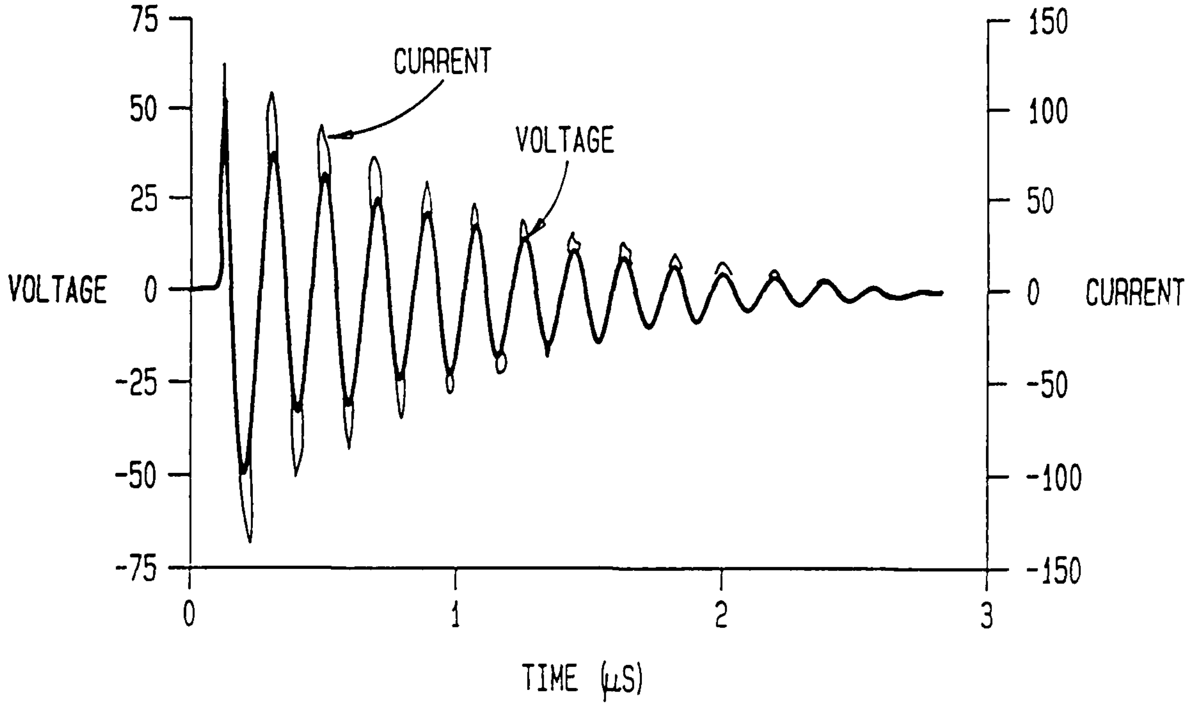

CURRENT
VOLTAGE
75
50
25
0
-25
-50
-75
VOLTAGE
150
100
50
0
-50
-100
-150
CURRENT
0
1
2
3
TIME (μS)

FIG. 2

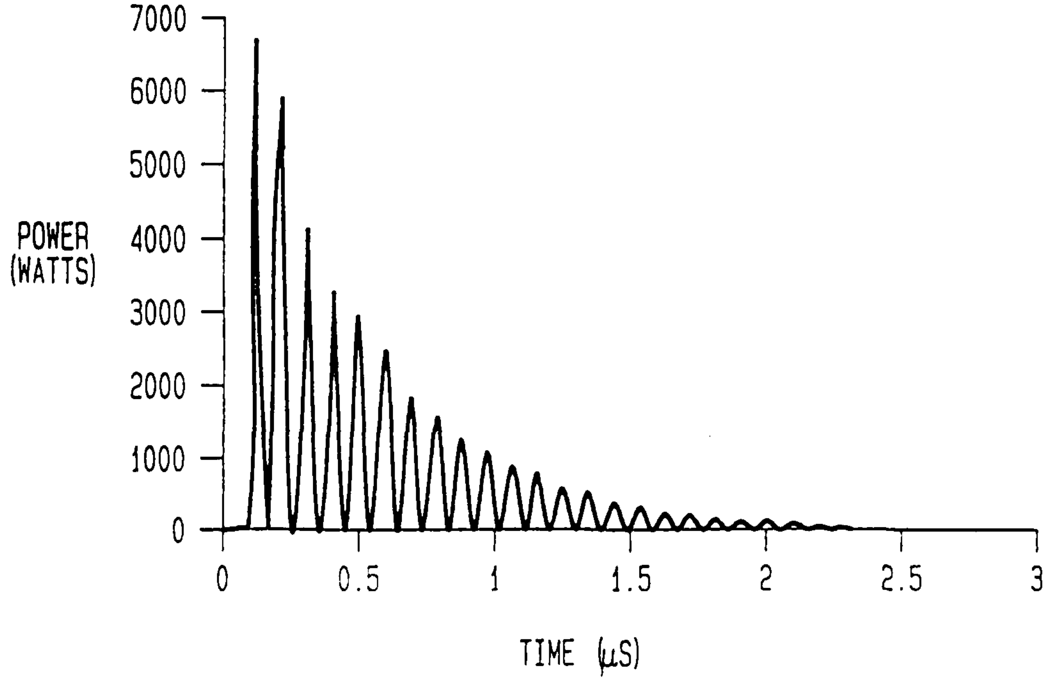
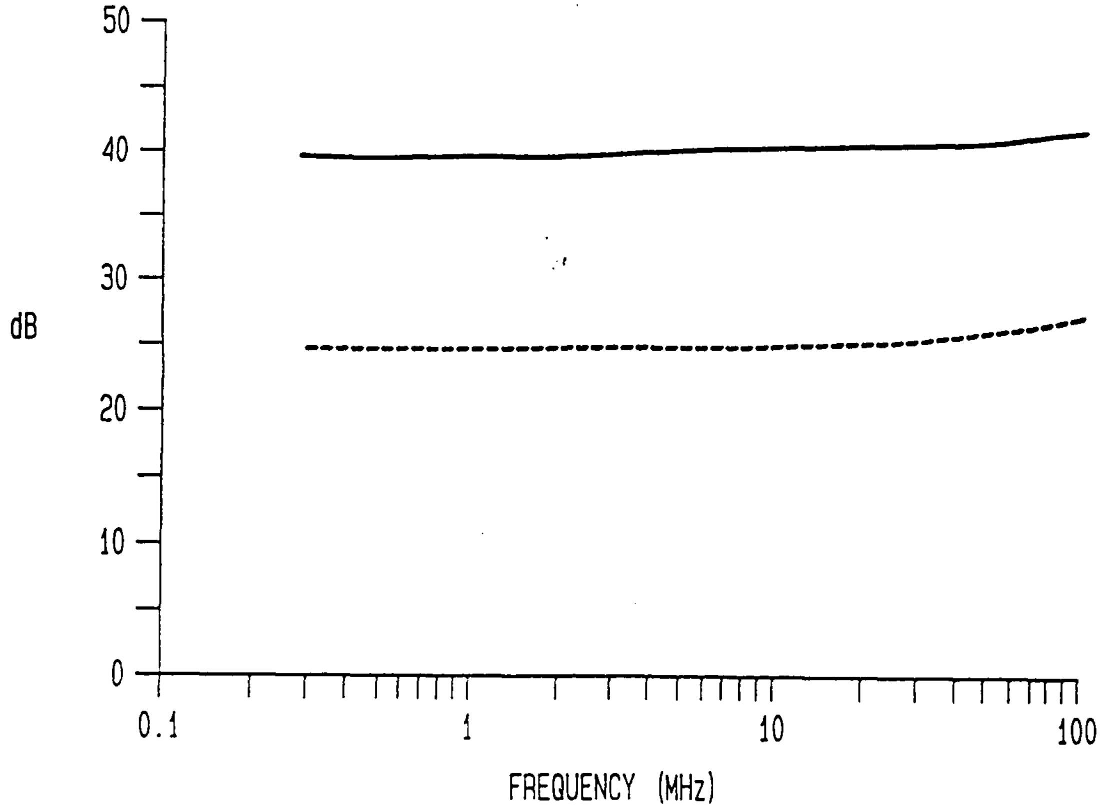

7000
6000
5000
4000
3000
2000
1000
0
POWER
(WATTS)
0
0.5
1
1.5
2
2.5
3
TIME (μS)

FIG. 3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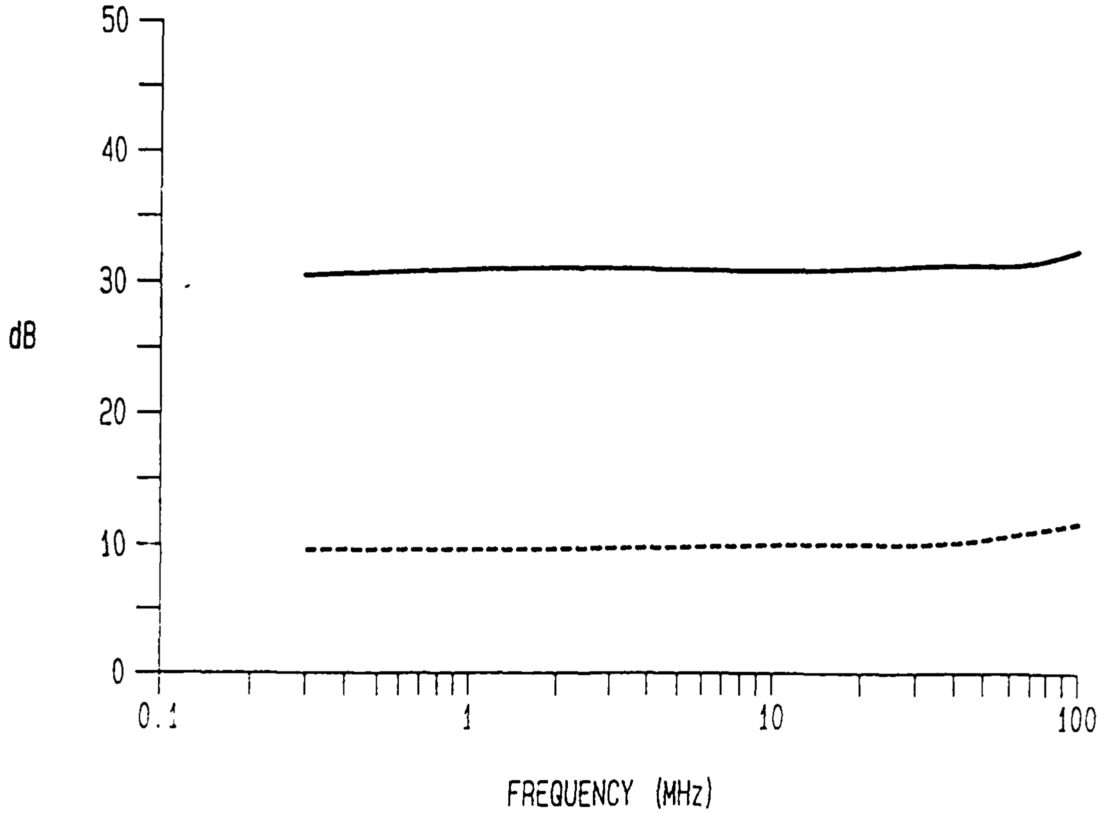
40
30
20
10
0
dB
0.1
1
10
100
FREQUENCY (MHz)

FIG. 4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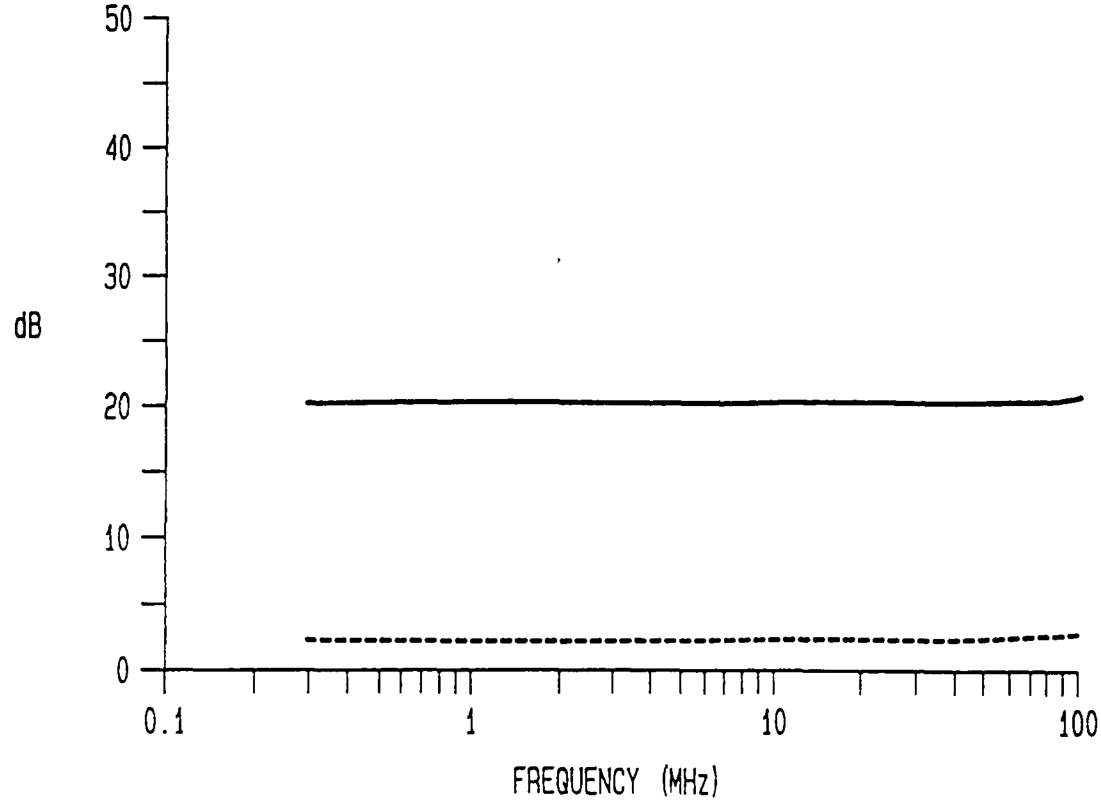
40
30
20
10
0
dB
0.1
1
10
100
FREQUENCY (MHz)

FIG. 5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40
30
dB
20
10
0
0.1
1
10
100
FREQUENCY (MHz)

FIG. 6

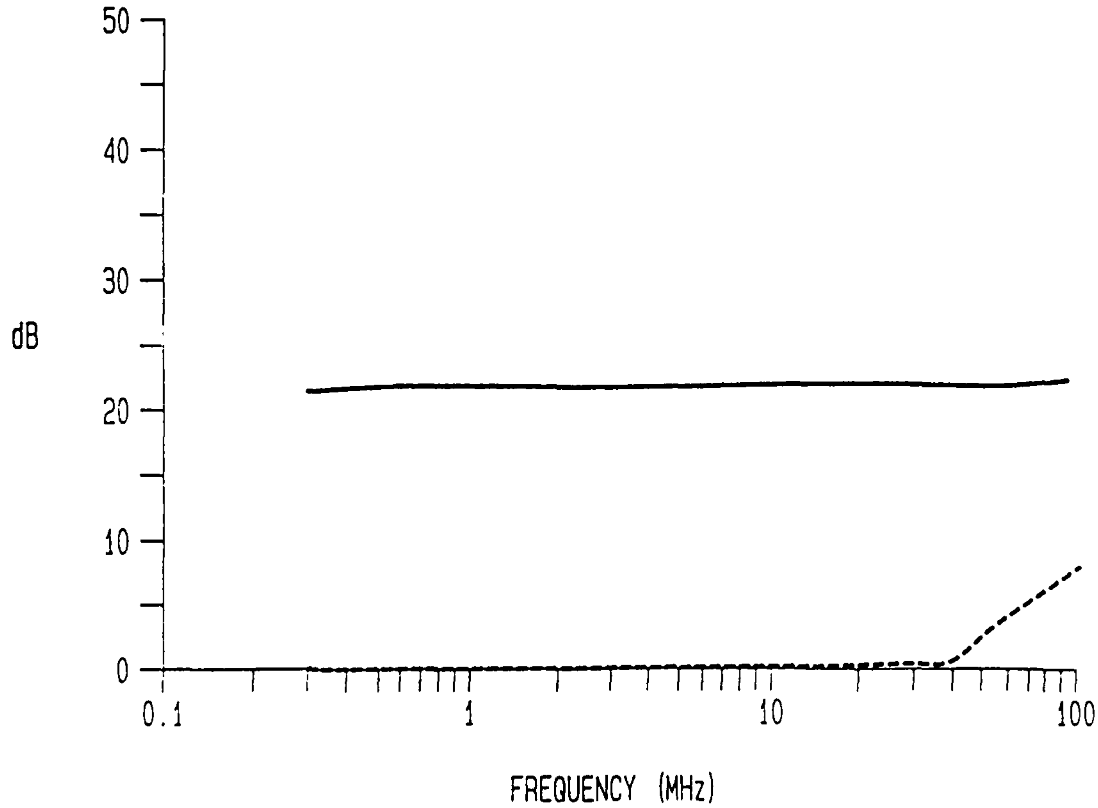
50
40
30
dB
20
10
0
0.1
1
10
100
FREQUENCY (MHz)

FIG. 7